CHAPTER

1 Foundation Investigations

Introduction

The ultimate strength and longevity of any structure depends on the adequacy of its foundation. Structure Representatives administering projects for the Office of Structure Construction have the responsibility of ensuring that the foundation work performed on their projects is of the quality necessary to allow each and every structure to sustain the design loadings throughout its useful life.

It is essential that Structure Representatives and all personnel working for the Office of Structure Construction commit themselves to learning the provisions within the *Standard Specifications*, Standard Plans, Contract Plans, Special Provisions and all relevant documents related to each contract they are working on. It has been proven time and time again that a thorough understanding of all documents related to a particular project and the effective use of this information leads to the effective administration of structure contracts.

Bridge Construction Memo 2-2.0 states:

> "It is the responsibility of the Structure Representative to clear up any problem areas prior to the start of construction, or as soon thereafter as possible."

In order to "clear up" problem areas, Structure Representatives must have a thorough understanding of the information contained within the contract documents. They must also know who to contact for further information or for advice on solving project problems.

This chapter will give an overview of the foundation investigation process. It will also show how the Log of Test Borings and Foundation Report for a structure project are developed. The goal of the chapter is to provide information related to the foundation investigation process that assists the reader in the interpretation and effective use of the Log of Test Borings and the Foundation Report during the administration of structure projects.

Who Performs Foundation Investigations

Foundation investigations for the various structures designed and constructed by the Engineering Service Center are normally performed by one of the two Foundation Investigation sections of the Office of Structural Foundations. The southern section in Los Angeles handles the investigations for projects to be constructed in Districts 7, 8, 9, 11, and 12. The northern section handles investigations in the remainder of the twelve Districts in the northern half of the State.

At times, the design of structure projects have oversight provided by the Office of External Liaison and Support through either the Consultant Contracts Management Branch, the Externally Financed Projects Branch, or the Local Assistance and Program Section. Foundation investigations for these projects are produced by consultant geotechnical companies. In these types of projects, the Log of Test Borings and Foundation Report for structures are reviewed by the Geotechnical Design Oversight Section of the Office of Structural Foundations.

Office of Structural Foundations Geotechnical Support

Personnel from the Office of Structural Foundations are available to provide support to Office of Structure Construction employees throughout the life of a construction project.

Structure Representatives are encouraged in Bridge Construction Memo 2-2.0 to schedule pre-construction meetings with personnel from the appropriate Foundation Investigation Section (Northern or Southern). The primary purpose of the pre-construction meeting would be to forge a good relationship with the Engineering Geologist that performed the foundation investigation, and to discuss the Foundation Report, Log of Test Borings, and any potential foundation problem areas in detail. This meeting may be invaluable to Structure Representatives in their efforts to recognize and discuss any potential foundation problems that may need extra attention during the foundation work on the project.

Once construction projects are under way, personnel from the Foundation Investigation Section lend their expertise when problems occur during foundation work. Engineering Geologists advise Structure Representatives over the phone and often visit projects to evaluate problems and recommend solutions. Structure Representatives are encouraged to inform the Foundation Investigation Section of any problems with structure foundations as

early as possible. Early notification often gives the Engineering Geologists the best chance of resolving foundation problems with the most economical solution.

Structure Representatives who have problems related to foundations on projects with oversight provided by the Office of External Liaison and Support; Externally Financed Projects Branch, Consultant Contracts Management Branch, or Local Assistance and Programs Section should contact the Liaison Engineer assigned to the project.

Foundation Investigation Overview

Once the Office of Structure Design begins the design of a new structure, widening, strengthening or seismic retrofit, the Project Designer sends in a Foundation Investigation Request to the appropriate Foundation Investigation Section. At that point an Engineering Geologist is assigned to perform the foundation investigation.

The Engineering Geologist assigned to perform a foundation investigation for a structure first collects as much information about the proposed site as possible. They normally accomplish this by reviewing preliminary structure plans, previously written foundation reports, As-Built plans, information on the historical seismicity of the area, and historical information on the subsurface conditions in the area of the proposed structure. This planning phase of the investigation gives the Engineering Geologist an idea of what to look for during their field work.

Once an Engineering Geologist collects all of the preliminary information, the Engineering Geologist lays out a boring pattern in relation to the structure's proposed foundation locations. The main goal in establishing a boring pattern for a foundation investigation is to collect as much subsurface information at the site as possible while making efficient use of the available drilling equipment and personnel.

Once the boring layout is established, the Engineering Geologist directs a foundation drilling crew during the performance of the subsurface drilling operation (to be described later in this chapter). The purpose of the subsurface drilling operation is to collect soil samples and perform in-situ testing at the site.

The soil samples collected during the subsurface drilling operation, results of in-situ tests, manual field tests, and various observations recorded by the Engineering Geologist provide the necessary information to develop the Log of Test Borings for the project.

Once the Log of Test Borings is completed, it is transmitted to the Project Designer. The Log of Test Borings is included as the last portion of the structure plans for the project.

After the Log of Test Borings is completed, the Engineering Geologist analyzes all the subsurface information collected and designs a recommended foundation for the structure. The recommended foundation type as well as other important pieces of information are compiled and included within the Foundation Report for the structure. This Foundation Report is also transmitted to the Project Designer.

Once the Log of Test Borings and Foundation Report are sent to the Project Designer, the design of the structure is completed using the foundation recommendations included in the Foundation Report. The Log of Test Borings is included in the project plan sheets, and the Foundation Report is included in the RE Pending File.

Subsurface Drilling Operation

The most important aspect of a foundation investigation is the subsurface drilling operation. Foundation drilling crews, led by the Engineering Geologist, conduct one or more drilling operations at the location of a proposed structure. The general purpose of the subsurface investigation is to determine the depth of rock, rock type and quality, soil types, soil strengths, and groundwater levels. The determination of these various parameters assists the Engineering Geologist in the development of a soil/rock profile. A soil/rock profile is a visual representation of the subsurface conditions interpreted from the subsurface investigations and laboratory testing. The soil/rock profile is included within the Log of Test Borings.

During the subsurface drilling operation, the Engineering Geologist is responsible for the evaluation of the soil and/or rock samples retrieved by the foundation drilling crew. After visual inspections and manual field tests, the Engineering Geologist will describe the soil or rock samples within the field logs. During the drilling operation, elevations of significant changes in material are noted and soil samples are usually taken from each different soil layer for laboratory testing.

The appearance and feel of the cuttings, difficulties or changes of the rate of advancement of the drilling tools, and other observations help the Engineering Geologist to estimate the strengths of the soil or rock layers. These observations are noted within the field logs. Any groundwater encountered during the drilling operation is also noted and special care is taken to accurately determine its elevation. The Engineering Geologist also determines whether or not the groundwater encountered is "perched" or in an "artesian" condition. These observations along with the various field and laboratory testing assist in the development of the soil/rock profile.

Two of the most important facets of the subsurface drilling operation are the recovery of soil samples retrieved during the drilling operations and the in-situ soil tests.

Soil samples are divided into two categories, disturbed and undisturbed. Disturbed soil samples are those which have experienced large structural disturbances during the sampling operation and may be used for identification and classification tests. Undisturbed samples are those in which structural disturbance is kept to a minimum during the sampling process. Undisturbed samples are used for consolidation tests and strength tests. Examples of these tests are direct shear, triaxial shear, and unconfined compression tests. The strength tests provide shear strength design parameters which are used in static analysis for pile foundations. Consolidation tests provide parameters needed to estimate settlements of spread footings or pile groups.

The most common method of retrieving a disturbed soil sample is with the split spoon sampler. The split spoon sampler is used for the Standard Penetration Test. As previously stated, disturbed samples, such as those retrieved from the split spoon sampler, are mainly used to assist in the soil classification and final identification of the soil.

Several types of soil samplers are used to retrieve undisturbed samples during subsurface investigations. Types include the California Sampler (which is used by the Office of Structural Foundations), the Shelby Tube, the Piston Sampler, and the Hydraulic Piston Sampler. Undisturbed soil samples provide the Engineering Geologist the best opportunity to evaluate the soil in its natural undisturbed state. This type of sampling usually provides the most accurate soil parameters once tests are performed.

In-situ tests are needed to provide soil parameters for the design of structure foundations, especially when standard drilling and sampling methods cannot be used to obtain high quality undisturbed samples. Undisturbed samples from non-cohesive soils are difficult to obtain, trim, and test in the laboratory. Soft saturated clays, saturated sands and intermixed

deposits of soil and gravel are difficult to sample and test in the laboratory. To overcome these difficulties, in-situ test methods must be used to measure soil parameters.

The most common in-situ test used during a subsurface investigation is the Standard Penetration Test (SPT). The test results in a penetration resistance value, "N". The "N" value can be used to estimate the angle of friction of a cohesionless soil, the unconfined compressive strength of a cohesive soil, and the unit weight of a soil (refer to Appendix A). Other in-situ tests are the static cone test, pressure meter test, vane shear test, and the borehole shear test. In-situ tests, such as the vane shear and Iowa borehole shear tests, provide soil shear strength parameters, such as cohesion, angle of internal friction, and shear strength.

These design parameters are used for static analytical design procedures for pile foundations and may also provide valuable information to a Structure Representative during the course of a construction project.

Log of Test Borings

After the subsurface investigation is complete, the Engineering Geologist develops the Log of Test Borings (Refer to Appendix A for examples). The Log of Test Borings includes a plan view showing the location of each boring retrieved during the subsurface drilling operation. It provides a graphic description of the various layers of geological formations, soils, and the location of the groundwater table (if encountered). Various soil and rock properties are also described. Each Log of Test Borings includes a standard legend on the left side of the sheet that describes the different symbols and notations used within the Log of Test Borings (refer to Appendix A for a standard Log of Test Borings legend).

Foundation Report

Once the Log of Test Borings is complete, the Engineering Geologist performing the foundation investigation develops the Foundation Report (refer to Appendix A for an example of a Foundation Report). The foundation report is basically a compilation of all the information retrieved during the foundation investigation and provides the Project Designer with a description and an evaluation of the geological formations and soils present at the site of a proposed project.

It also describes and evaluates any seismic hazards that may be present at the site, such as the amount of ground shaking that can be expected and the possibility of liquefaction occurring at the site. The report gives recommendations to the Project Designer as to the type of foundation that should be used for the proposed structure and also recommends the seismic data, such as peak horizontal bedrock acceleration, that should be used for the seismic analysis to be performed. The report includes the recommended elevations for spread footings and pile type and tip elevations.

Most reports include special comments regarding anticipated constructability problems, such as caving, soil compaction problems, expected variations in pile driving, and potential problems due to groundwater. This section of the report may even suggest that job-specific specifications be included within the contract Special Provisions. The Structure Representative should pay particular attention to these comments. Advance knowledge of potential problems during foundation work allows for more effective problem mitigation.

The Foundation Report is normally included in the RE Pending File. Structure Representatives should contact the Office of Structure Construction in Sacramento if they do not receive a copy of the Foundation Report for any project assigned to them.

In the early stages of every project, the project plans should be reviewed to verify that the footing elevation, pile tip elevations, and type of piling recommended in the Foundation Report are shown on the contract plans. In addition, the Structure Representative should confirm that any suggested specifications or design features mentioned within the special comments section of the Foundation Report are included in the contract plans and specifications. Personnel from the Foundation Investigations Section and the Project Designer should be consulted if there are any discrepancies.

If there are special comments regarding constructability problems within the Foundation Report, these issues should be discussed with the Contractor as early as possible. Once the Contractor begins work, the Structure Representative should observe if and how the Contractor makes preparations to deal with the constructability problems that they were informed of. Good documentation of all conversations with the Contractor on these issues will help in the evaluation of any potential claims submitted by the Contractor.

Applicability of the Log of Test Borings and Foundation Report to the Contract

It is very important for Structure Representatives, as well as all Structure Construction employees, to be aware of how the *Standard Specifications* interpret the applicability of the Log of Test Borings, Foundation Report, or any record of subsurface investigation produced by the State. Section 2-1.03 of the *Standard Specifications* describes how these documents should be viewed by all contractors performing work for the State.

Section 2-1.03 of the *Standard Specifications* states that the Contractor has an obligation to examine the site of the work, the plans, and the specifications. From this examination, contractors are to make their own determination as to what conditions they may encounter while doing the proposed work. This section also states that bidders can inspect any records compiled by Caltrans, but the use of this information is only for the purpose of study and design and that they are not part of the contract documents. Caltrans assumes no responsibility as to the sufficiency or adequacy of any of its investigations and this section states that there is no warranty or guaranty that any conditions indicated by a subsurface investigation performed by Caltrans are representative of the conditions throughout a construction site. This section also describes the Log of Test Borings and any other geotechnical data obtained as being Caltrans' opinion as to the character of the materials encountered during its investigations at the site of the work.

Section 2-1.03 also very clearly states that contractors should make whatever independent investigations that they feel are necessary to inform themselves of the conditions to be encountered. Contractors should only be using the Log of Test Borings and any other records of subsurface investigations compiled by Caltrans to supplement their own site investigations.

Basic Soil Properties

In order to understand and interpret a Log of Test Borings and Foundation Report, it is important to have a basic understanding of the different types of soils that may be encountered during foundation investigations.

There are a number of soil classification systems used in the engineering industry. Most of these systems are based on those properties which are most important in the phase of engineering for which the classification was developed.

The Office of Structural Foundations has adopted a classification system based on the Unified Soil Classification System. All Foundation Reports and Log of Test Borings now follow this classification system.

CLASSIFICATION	DEFINITION
Boulders	Particles of rock that will not pass a 12-inch square opening.
Cobbles	Particles of rock that will pass a 12-inch square opening but will be retained on a 3-inch sieve.
Gravel	Particles of rock that will pass a 3-inch sieve but will be retained on a No. 4 sieve.
Sand	Particles of rock that will pass a No. 4 sieve but will be retained on a No. 200 sieve.
Silt	Soil passing a No. 200 sieve that is nonplastic or very slightly plastic and exhibits little or no strength when air dried.
Clay	Soil passing a No. 200 sieve that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when air dried.
Organic Soil	A soil with sufficient organic content to influence the soil properties.
Peat	A soil composed primarily of vegetable matter in various stages of decompostion. This soil usually has an organic odor, is dark brown to black in color, has a spongy consistency, and a texture ranging from fibrous to amorphous.

Engineering Geologists often describe soils with a series of descriptive adjectives before the noun. An example of this would be:

"Slightly compact, dark gray, micaceous Clayey Sand."

This statement describes a material that is predominantly made up of sand, but has enough clay within it to make it a little plastic when handled.

Visual inspection is generally sufficient to differentiate between the coarse grained soils. However, the distinctions between soil particles such as silts and clays can be difficult. Several simple field tests utilizing measures of settling, plasticity, dry strength, and permeability characteristics of the soil permit a more accurate classification of these soils.

Once a soil is immersed in water, sand grains settle rapidly, usually in less than one minute. Silt settles more slowly, usually from 10 to 60 minutes. Clay will remain in suspension for several hours.

Sand, being non-plastic, will not form a plastic thread by rolling it on a smooth surface. Silt will form a thread when rolled, but it is weak and crumbles as it dries. Clay forms a plastic thread of high strength, which dries slowly and usually becomes stiff and tough as it dries.

Sand has no unconfined dry strength. Silt has very little dry strength and easily powders when rubbed. Clay has a high dry strength and will not powder easily.

A rough indication of the permeability of a soil is shown by its reaction to shaking or patting. When a small amount of silt is subjected to this type of movement, water appears on the surface, which assumes a "livery" appearance. Upon shaking or patting clay, this reaction occurs slowly or not at all.

Geotechnical Drilling and Sampling Equipment

Many different pieces of equipment are used by foundation drilling crews and engineering geologists to obtain samples and evaluate subsurface conditions.

It is important for Structure Construction employees to have a good working knowledge of the equipment used during the subsurface drilling operation for their projects. The different pieces of equipment used to perform the drilling operation have different levels of reliability. The reliability of the equipment used during the subsurface investigation is an important factor for the Structure Representative to take into consideration during the early phases of a project.

The following is a brief description of the various pieces of equipment used by the Office of Structural Foundations as well as consultant geotechnical companies.

EQUIPMENT	DESCRIPTION
$2^1/_4$-Inch Cone Penetrometer	The $2^1/_4$-Inch Cone Penetrometer is an in-situ testing apparatus that drilling crews use during subsurface drilling operations. The test is conducted using an air compressor to drive the testing apparatus through the soil. The Engineering Geologist records the drilling rate in seconds per foot of penetration. The results of the test are shown graphically to give an indication of the soil's varying densities as the cone penetrates the different layers of soil.
Sample Boring	The Sample Boring is a manual boring technique where a 1-inch sample tube is driven using a 28-pound hand hammer with a 12-inch free fall. The blows per foot are recorded by the Engineering Geologist in a manner similar to the Cone Penetrometer test. This technique is used only for soft soil sites and in areas where it is difficult to get a drilling rig on the site.
Rotary Boring	The Rotary Boring is a rapid drilling method used for penetrating soil and rock. Borings up to 200 feet and more in depth can be taken using this method. The hole is advanced by the rapid rotation of the drilling bit, and water or drilling mud is used to flush out the drill cuttings and to lubricate the cutting tool.
Auger Borings	An Auger Boring can be advanced without water or drilling mud and provides a dry hole. It gives a good indication of material that is likely to cave in during an excavation or drilling operation. It also gives an accurate reading of where the groundwater elevation is. Most equipment can drill to depths of 100 to 200 feet.
Diamond Core Boring	A Diamond Core Boring is used when rock is encountered during a drilling operation. It allows the drilling crew to recover continuous sections of rock cores. The Engineering Geologist can inspect the cores to determine the competency of the rock.
Electronic Cone Penetrometer	The Electronic Cone Penetrometer is an apparatus that drives a cone into soil similar to the $2^1/_4$-inch cone penetrometer, but it is capable of providing other soil parameters, such as soil type, shear strengths, stiffness, bearing capacities, pore water pressures, relative densities, and shear wave velocities.
Bucket Auger	The Bucket Auger is a drilling tool that is used to excavate a larger diameter hole (24 to 36 inches). It is considered to be the best indicator for the presence of cobbles and boulders. It is also a good indicator for the presence of material that is likely to cave in during an excavation.